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ELECTRIC & MUSICAL INDUSTRIES LTD.

RECORDS & INTERNATIONAL DIVISION.

Recording Equipment Production Dept.

THE E.M.I. "STEREOSONIC" RECORDING CIRCUITS -----

SUM & DIFFERENCE, SPREADER AND SHUFFLER.

Summary.

The principles of the E.M.I. "Stereosonic" recording circuits, which are shown in block form on Drawings REDD.C5/D1 & D2, have already been fully explained in previous publications. This pamphlet therefore deals only briefly with the advantages which are gained by the use of these circuits, and then goes on to describe the circuits in detail.

Advantages.

The main advantages which are gained by the use of the special E.M.I. "Stereosonic" circuits may be summed up as follows:-

(a) Faders.

No matter how closely matched a coupled pair of stud type faders may be, it is inevitable that discrepancies between them will arise as the wiper arms pass over the contact studs and a pair of adjacent studs thus become momentarily short-circuited on one fader but not on the other. If such faders are used in the conventional way in the left and right channels, this will give rise to an apparent shift in the angle of the source as the faders are operated. Unless the decibel steps on the faders are very small, this defect may be serious.

If, however, the pair of faders is included within Sum & Difference circuits, the effect is reduced to a slight widening or narrowing of the total apparent angle, central sources remaining completely unaffected.

(b) Spreader.

The Sum & Difference circuits provide a convenient place at which to insert the Spreader, which is a device for artificially altering the apparent total included angle. When the Spreader is used in this way, it also becomes possible to change the total included angle actually occupied by the orchestra, and thus the stereo microphone may be placed nearer to, or further from, the source than would otherwise be the case. The flexibility which this gives in dealing with awkward studio acoustics is obvious.

(c). Shuffler.

The S. & D. circuits also permit the use of the Shuffler, which may be described as a device for counter-acting one of the main disadvantages of the use of two loudspeakers (as compared with headphones) for stereo reproduction. This disadvantage arises from the fact that the left ear, for example, does not hear only the sound from the left hand loudspeaker, but also a large proportion of the sound from the right hand loudspeaker, and from the fact that this effect diminishes at the higher frequencies.

SUM & DIFFERENCE TRANSFORMERS.

In order to obtain a clear idea of the operation of the Sum & Difference transformer circuits, please refer to Drg. REDD.17/C7. This drawing illustrates the case for ideal transformers, i.e., transformers with a perfect frequency response, no core loss and no loss due to the resistance of the windings.

For the purposes of this diagram, it is assumed that a crossed figure-of-8 (crossed cosine) microphone, with a perfect polar characteristic, is in use, and that a constant source of sound is located firstly at the full left position (i.e. 45° to the left of the centre line), secondly on the centre line, and thirdly at the corresponding right hand position. Taking, first of all, the case for a left hand source, it will be seen that the input consists of a signal on the left hand channel and nothing on the right hand channel. After the first pair of Sum & Difference transformers, this is changed into two equal signals. It will be seen that the transformer ratios are so arranged that the circuits are matched, and that the power is equally divided between the Sum & Difference channels. In other words, each carries a signal which is 3 dB below the original (left hand) input signal. The drawing gives a useful mnemonic for dealing with S. & D. circuits which have their connections made in the particular way shown, namely that:-

$L + R = S.$ $\qquad\qquad$ $L - R = D.$

After passing through the second pair of Sum & Difference transformers, the original signal is reconstituted, with the whole of the signal on the left hand channel and nothing on the right. Again, Drg. REDD.17/C7 shows this effect, and gives the useful mnemonic:-

$S + D = L.$ $\qquad\qquad$ $S - D = R.$

The reader may be forgiven if, at this point, he asks, "What, then, is the purpose of these circuits ?". The answer, of course, is that, in this over-simplified treatment, no mention has been made of the Faders, the Spreader and the Shuffler, all of which are normally included between the first and second pairs of S. & D. transformers.

Next, consider the case for a central signal. The two microphones have their axes at 90° to each other and, still assuming that each has a perfect figure-of-8 characteristic, it is easy to see, by drawing the vectors, that each channel will receive a signal voltage which is equal to the original left hand signal divided by $\sqrt{2}$. Putting this in another way, the available power from the source is divided equally between the two microphone channels, each of which is 3 dB down on the corresponding "left hand only" case. With two equal in-phase signals arriving from the input, at the first S. & D. transformers these two signals are combined in the Sum channel and there is no resultant signal in the Difference channel. When the signal in the Sum channel reaches the second S. & D. transformers, it divides equally between the final L and R channels.

Taking now the third case, that for a purely right hand signal, it will be seen that, as before, this signal is divided equally between the S. & D. channels, but that, under these conditions, the signal in the Difference channel is 180° out-of-phase. After passing through the second S. & D. transformers, the signal is restored to the R channel only.

It will be seen, therefore, that the S. & D. circuits in themselves have no effect upon the signals from the stereo microphone, and there would be no advantage in using them were it not for the fact that they enable the other circuits to be employed.

As mentioned before, Drg. REDD.17/C7 does not include the effect of the losses of the S. & D. transformers. Drg. REDD.37/D44 shows how a shunt resistance is used to compensate for the resistance of the windings and thus maintain the impedance substantially constant at 200 ohms, giving an effective loss of 1.7 dB for each transformer.

Before proceeding with the description of the Spreader and the Shuffler, it is a useful exercise to consider the effect of introducing loss into the Sum & Difference channels respectively.

This effect is shown on Drawing REDD.C34/C1 which should be compared with Drg. REDD.17/C7. Taking first of all the case for a purely left hand source, there are equal in-phase signals in the Sum & Difference channels. If 6 dB of attenuation is now introduced into the Difference channel, the signal voltage in that channel will be reduced to one half of what it was previously. After passing through the second pair of Sum & Difference transformers, instead of having all the signal on the left hand channel and nothing on the right, it will be seen that one quarter of the signal has been taken away from the left channel and now appears on the right. This is equivalent to saying that the final left hand signal has been reduced by $2\frac{1}{2}$ dB and that cross-talk $9\frac{1}{2}$ dB down now appears on the right. Obviously, the apparent position of the source will move from the extreme left towards the centre.

Next consider the case for a central source. As there is no signal in the Difference channel, introducing attenuation into that channel will have no effect.

For a purely right hand source, the signals in the S. & D. channels are equal, but out-of-phase. It will be seen that introducing 6 dB of attenuation into the Difference channel produces results which are exactly comparable with those obtained from a purely left hand source.

Summarising the above, it will be seen that introducing loss into the Difference channel causes a left hand source to move apparently towards the centre, has no effect upon a central source, and causes a right hand source to move apparently towards the centre. It follows that the overall effect upon, say, an orchestra is to decrease the total apparent angle.

If we now start again with a purely left hand source, but this time introduce the 6 dB of attenuation into the Sum channel, it will be seen that the effect is similar to that obtained previously except for the fact that the resultant cross-talk in the right hand channel is out-of-phase. This has the effect of making the apparent position of the source move to a new position further out than the left hand loudspeaker.

For a central signal it is obvious from Drg. REDD.17/C7 that introducing loss into the Sum channel has no effect other than to reduce the total signal level.

For the right hand signal, the results are similar to those for the left hand signal, except, of course, that the out-of-phase cross-talk appears on the left channel.

Again summarising, the introduction of loss into the Sum channel causes a left hand source to move outwards, has no effect on a central source (but see below), and causes a right hand source to move outwards. The overall effect is therefore to increase the total apparent angle.

SPREADER.

If infinite attenuation were to be introduced into the Difference channel, the stereo effect would be removed, both loudspeakers would emit identical in-phase signals, and the effect would be similar to a point sourcein the centre. Another way of putting it is to say that the cross-talk would then be 100%.

In the Spreader, a partial use is made of this effect by introducing 2, 4 or 6 dB of attenuation into the Difference channel. In this way, the effective total apparent angular spread is reduced, (by anti-clockwise rotation of the control knob).

Clockwise rotation of the knob will introduce a similar amount of attenuation into the Sum channel, thus causing a small proportion of the signal on, say, the Left Channel to be diverted to the Right channel, where it appears out-of-phase. This causes the apparent total angular spread to be increased.

The use of the Spreader, which operates only when S. & D. circuits are in use, is further explained on Drgs. REDD.R1/D1, D2 & D3, which also give details of the increased freedom in placing the orchestra mentioned earlier.

The type of Spreader in which up to 6 dB of attenuation is introduced either into the Sum or into the Difference channel suffers from the slight disadvantage that the overall sensitivity is reduced somewhat when the attenuation appears in the Sum channel. If the circuit conditions permit, it would be preferable to use, say, a fixed loss of 6 dB in the Sum channel and a loss which was variable from 0 to 12 dB in the Difference channel.

The uncontrolled use of the Spreader for increasing the apparent total angular spread by introducing out-of-phase cross-talk is not recommended. Under all normal conditions, a full spread can be obtained quite easily by suitable placement of the orchestra, and the need for artificial spreading, therefore, does not really arise. It is recommended therefore, that artificial spreading should be used only when the orchestra or group of performers occupies only a small proportion of the total permissible angle, in other words, when the microphone is well back.

To sum up, use the Spreader carefully and only after due consideration of the information contained on the drawings.

SHUFFLER.

Summary.

The Shuffler should not be confused with the circuit of the same name invented by the late A.D. Blumlein, the purpose of which was somewhat different. The present Shuffler is really a device for producing a small, controlled amount of in-phase cross-talk at medium and high frequencies, without introducing unwanted phase differences between the two channels. This is achieved by means of a slight top cut in the Difference channel, together with suitable phase compensation networks.

Action.

The action of the Shuffler can best be explained as follows.

Suppose that an instrument is located half way between the extreme Left and the centre. When notes of very low frequency are played on this instrument all is well, but when higher and higher notes are played it appears to move out towards the left. This is due to the fact that the low frequency notes are heard substantially equally well with both ears, but the higher frequency notes are partly masked by the human head and are therefore heard better with the left ear. In this example, the Shuffler counteracts this effect by taking a little of the higher frequency signals away from the Left Hand channel and applying them to the Right Hand channel. In this way, the apparent angle of the source is made to remain constantwith increase in frequency. Thus, the Shuffler may be described as a device for producing deliberate cross-talk at the higher frequencies. Drg. REDD.C27/D1 shows that this effect is centred at 700 c/s, and that it begins to be appreciable at frequencies as low as 100 c/s.

Circuit Principles.

It is impossible to produce a circuit which affects the frequency response without at the same time also affecting the phase of the signal, and this phase change will be most marked at the frequency at which the circuit operates.

If we take as an example the 3 dB top cut circuit used in the Difference channel of the Shuffler and ignore for the moment the resistance of the inductance and also the resistance connected across the condenser, it is easy to see that at very low frequencies, (where the reactance of the condenser becomes very great and that of the inductance very small), the circuit becomes equivalent to a straight-through pair of wires, and will thus have no loss. At very high frequencies, (where the reactance of the condenser is negligible and that of the coil is very great), the circuit will become equivalent to a simple 3 dB "T"-pad. It follows, therefore, that at these extremes of frequency there will be no phase change due to the circuit. There will, however, be a phase change at all frequencies at which the circuit is operating but at which it has not reached its full effect, and this change will be a maximum at 700 c/s, which is the mid-point, or frequency at which $1\frac{1}{2}$ dB of top cut is obtained. If we could put a similar amount of phase change into the Sum channel, then all would be well, but unfortunately this cannot be done without at the same time introducing a change in the frequency response, and this is not required.

The method adopted, therefore, is firstly to add to the top cut circuit a further circuit which, so to speak, carries on the phase change started by the top cut circuit.

This is accomplished by means of an all-pass network, the effect of which is to cause the overall phase angle to change from 0° at very low frequencies to 180° at very high frequencies, 90° of phase change being obtained at 700 c/s. It is then a comparatively simple matter to insert into the other (Sum) channel another all-pass network operating at a slightly lower frequency than the one in the Difference channel. The phase-change on both channels will then be almost identical, i.e., there will be substantially no relative phase change between them.

Again ignoring the resistor connected in parallel with the condenser, if we examine the circuit of either all-pass network, it can be seen that at very low frequencies it becomes equivalent to a straight-through pair of wires. At very high frequencies, (where the reactance of the condenser is negligible), the circuit becomes equivalent to a simple transformer with the lower side connections commoned. At V.L.F., therefore, there will be no phase change, whereas at V.H.F. there will be a phase change of 180°.

On the top cut and on both the all-pass networks, it will be seen that there are resistors connected across the condensers. All practical inductances have a certain amount of resistance, and this resistance appears in series with the top arm and would therefore make the circuit impedance rise above the nominal 200 ohms. This would be particularly undesirable at low frequencies, at which the reactance of the windings of the preceding and following S. & D. transformers is falling off. To compensate for this effect, shunt resistors are connected across the condensers and are of such a value that both circuits become equivalent to 0.6 dB 200 ohm attentuators at V.L.F. This standing loss decreases slightly at higher frequencies, at which the shunt resistors become by-passed by the condensers.

Microphones.

E.M.I. Stereo microphone assemblies are carefully checked for relative polarity before despatch. They obey the conventions shown on Drgs.REDD.C5/D1 and D2.

Should it ever be necessary to check a stereo mic. for relative polarity, thic can be done quite easily by seriesing or paralleling the two outputs. Condenser mics. have sufficient sensitivity to enable the combined output voltage to be read on most valve voltmeters when someone is speaking close to the microphone assembly. By rotating the latter whilst speaking in a steady voice, it is easy to see which sectors produce in-phase and which produce out-of-phase signals.

IMPEDANCE MATCHING.

It is essential that the E.M.I. "Stereosonic" circuits should be fed from matched resistive source impedance, each of 200 ohms. The design of all these circuits is such that the impedance looking back into them is then 200 ohms resistive. The terminating impedances are therefore not critical and may be of any value provided they are resistive or substantially so.

IMPEDANCE MATCHING (Contd).

Usually, each of the terminating impedances is 200 ohms, but higher values are used in some apparatus and the terminations are omitted altogether in other equipment.

TESTING.

A clear idea of what to expect is essential for the efficient testing of any circuit. After reading the preceding sections, the engineer will have a good idea of what to anticipate on these circuits, but it is hoped that the following notes may prove useful:-

Sum & Difference Transformers.

Two possible ways of testing S. & D. transformers are suggested:-

(a) By sending a signal to one side of a pair of transformers and verifying that the signal divides equally and in phase at the outputs.

(b) By sending a signal to one side of a group of four S. & D. transformers and verifying that the signal is restored to the same side at the final output.

For both cases, it is essential that the unused input should be terminated by a dummy source impedance of 200 ohms. In actual mixers, where the S. & D. transformers are fed from preceding microphone amplifiers or other circuits, these conditions will be provided automatically. Also, both outputs should be terminated by the same impedance during the test.

When carrying out tests such as the above, where the S. & D. transformers form part of a complete equipment, it will be appreciated that it is necessary to keep both faders at the same setting. This can readily be seen from Drg. REDD.17/C7, taking the case for, say, a "left hand only" signal. (It may be worth recalling here that this drawing indicates only the main phase of the signals, i.e., whether they are in phase or 180° out-of-phase. This greatly simplified treatment is only valid for the case when identical in-phase signals appear at the inputs).

Cross-talk should be negligible at medium frequencies, but will increase at very low frequencies where the reactance of the S. & D. transformers falls off, and at very high frequencies where the self-capacity of the windings begins to take effect.

Spreader.

On all later equipments, the inputs and outputs of the Spreader are brought out to test sockets, and it is then an easy matter to test the Spreader as a simple 200 ohms unbalanced attenuator. An examination of the circuit diagram will show what to expect.

Alternatively, the Spreader may be tested within Sum & Difference, as part of a complete equipment. In this case, it is usually the cross-talk produced by the Spreader which is measured. On most equipments, it is possible, merely by turning a switch, to combine the left and right final outputs so as to form a mono signal, and this facility enables a rough check to be made of the relative phase when carrying out the foregoing tests. Obviously, two in-phase signals will add, whereas two out-of-phase signals will subtract. Engineers are recommended to make a note of typical test figures obtained in this way, so that spot checks can be made on the equipment in case of doubt.

Shuffler.

Remarks somewhat similar to those for the Spreader also apply to the Shuffler, which can be routine tested either by measuring the frequency response of the Shuffler circuits alone, or alternatively by measuring the cross-talk produced when the Shuffler is inserted at its normal position in the circuit. Again, it is useful to operate the "Stereo - Mono" coupling switch and verify that signals which are supposed to be in-phase do, in fact, add. Again, the engineer is recommended to keep a note of such figures for use in cases of suspected trouble.

For full and rigorous testing of the Shuffler, equipment for measuring the phase angle of the outputs at all frequencies is required, of course, but the above simple checks will suffice to indicate whether anything has gone seriously wrong.

General Recommendations.

As an alternative to the above methods of testing, it is possible, of course, to send signals simultaneously to both channels. If equal in-phase signals, both derived from the same tone generator, are used, this would give, for example, a combined signal in the Sum channel and nothing in the Difference channel. However, such methods lead to considerable complications and they are not recommended until the engineer has become very conversant with the equipment. If the main coupling switch is set to "Mono", as before, this test will, however, have the major advantage of immediately showing up any poling errors in the equipment, and it is recommended that such a test should be made after any part of the apparatus, including jumper leads, has been serviced.